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Performance evaluation of untreated sugarcane bagasse ash as partial replacement of cement on setting time and compressive strength of M15 concrete

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Abstract: Due to its escalating cost, cement, the primary component of concrete, has become a significant issue in Nigeria over time. The use of agricultural wastes such as cow bones, periwinkle shells, rice husks, and sugarcane bagasse as additives to partially replace cement has been made possible by scientific efforts to find alternative and effective materials from large deposits of agricultural wastes. This study examines how adding sugarcane bagasse ash (SCBA) to concrete affects its strength properties. Sugarcane bagasse ash was successfully included in various amounts (0, 2.5, 5.0, 7.5, and 10% by weight of cement). A mix design of 1:2:4 (M15) grade and a water-cement ratio of 0.5 was used to cast 60 concrete cubes measuring (150 x 150 x 150) mm. Concrete's workability and setting time were improved by adding sugarcane bagasse ash to the cement. The outcome revealed a reduction in concrete density with an increase in percentage replacement of sugarcane bagasse ash. Addition of sugarcane bagasse ash to cement increased the concrete's workability and speed of setting. The results showed that concrete density decreased as sugarcane bagasse ash replacement percentage increased. This is not unrelated to the fineness of sugarcane bagasse ash, which makes the cementitious matrix and aggregate interface more intense and lighter. Concrete's compressive strength was discovered to be decreased by the usage of sugarcane bagasse ash. Between 0, 2.5, 7.5, and 10% sugarcane bagasse ash, the average compressive strength measured at 28 days was found to be 25.93, 25.19, 23.70, 20.30, and 18.96 MPa, respectively. 10% sugarcane bagasse ash concentration was suggested as the optimal level to employ for improving concrete characteristics.

Keywords: Sugarcane bagasse ash, cement, concrete, setting time and compressive strength

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1. Introduction

A perennial tall grass with the botanical name of sugarcane, *Saccharum officinarum*, thrives in tropical climates and the (Pandey et al., 2018) estimated average of 30% bagasse ash from sugarcane and 2.48% ash content is produced in Nigeria (Sadeeq et al., 2015). Due to its highly energy-intensive manufacturing process, sugarcane ash has only lately been studied for its pozzolan capabilities. It has been discovered that certain characteristics, such as setting time, compressive strength, and water resistance, improve with percentages and fineness (Olatokunbo et al., 2018; Reddy et al., 2016). Utilizing agricultural wastes as substitutes for cement could reduce the price of making concrete and the environmental harm that comes with disposing of these wastes (Debbarma et al., 2020; Shafigh et al., 2014). The emphasis on reducing cement is supported not just by economic and environmental measures, but also by its connection to various qualities of both newly-poured and cured concrete (LeBow, 2018).

The basic characteristics of the mix, such as workability, drying shrinkage, durability, and compressive strength, are significantly impacted by the cement's production (Gupta & Vyas, 2018). Khalil et al. (2021) concluded that up to a maximum of 10%, when replacing more cement with SCBA, the workability of concrete was not significantly reduced. SCBA also exhibited a satisfactory elastic modulus (Xu et al., 2018; Sharma & Kumar, 2021). Bagasse, a byproduct of sugarcane, can also help to minimize permeability and cracking while maintaining workability (Bheel et al., 2022). Shafiq et al. (2018) conducted an experiment to see how replacing SCBA would affect cement's fresh qualities up to 30% at 5% intervals. The results showed that SCBA significantly increased the consistency (water requirement) by 30-45% while delaying both setting times by 180-297 and 390-450 minutes, respectively (Olu et al., 2020).

Mangi et al. (2017) found out that the compressive strength created by replacing 10% of the fine aggregate with SCBA was higher than the control, however every additional increase in SCBA content caused a drop in its strength. Due to the pozzolanic properties of SCBA, the rate of strength gains of the mixes containing it increased at later times. This study came to the conclusion that aggregate replacements of 10–20% can be successfully replaced with untreated SCBA without suffering significantly from workability and strength loss (Joshaghani & Moeini, 2017; Thomas et al., 2021). The optimum amount of SCBA boosts the compressive strength of concrete, however as the replacement percentage increased, the strength attribute decreased (Cheah et al., 2019). On the other hand, the optimal replacement level changes as curing ages increase. This phenomenon is explained by the pozzolanic processes that take place in concrete.

The goal of this study is to identify the SCBA process condition with the maximum pozzolanic reactivity and to analyze how it affects the physico-mechanical characteristics of cement.

2. Materials and methods

Portland Limestone cement from the Dangote brand with a specific gravity of 3.15 and a grade 43 was employed for this experiment in line with BS EN 197-1 (2011). Sand was sourced from a construction site at Surulere, Lagos, Nigeria, made up the fine aggregate. The granite was made of nominally 20mm-sized crushed stones that came from an Ikorodu, Lagos, and quarry. The coarse aggregate was cleaned and dried in accordance with BS EN 933-1 (2012) to be free of contaminants, whereas the fine aggregate had particles ranging in size from 2 mm to 150 mm. To mix concrete and cure specimens in line with BS EN 1717, the laboratory has access to potable water with a normal pH (BS EN 1717, 2000). Bagasse made from sugarcane came from a trader in Mile 12, Lagos with specific gravity of 1.94. Bagasse (500g) of sugarcane waste was dried outside in order to lower the moisture level. Dry bagasse was ground up and heated in an electric furnace for six hours at 700°C. By putting sugarcane bagasse through sieves measuring 425, 300, 90, and 45 m, respectively, unburned particles that had a larger percentage of carbon were taken out. By obtaining finer ash particles, this will enhance the pozzolanic activity of concrete. In this experiment, the SCBA made from sugarcane bagasse and with a water/cement ratio of 0.5 was mixed in a ratio of 1: 2: 4 (cement: sand: granite) by mass. Portland Limestone cement-43 was substituted with sugarcane ash in Table 1 at various intervals of 0:100%, 2.5:97.5%, 5:95%, 7.5:92.5%, and 10:90%. Trial mixtures were put through initial and final setting times of cement paste and that of fresh concrete using Vicat apparatus in a well-contained environment. Prior to beginning the experimental work, the slump test (workability) was established. The results of the slump test are used to gauge the consistency and workability of new concrete. BS EN 12350-2 was followed in performing the test (BS EN 12350, 2009). The interior surfaces of the cast iron mold were covered in machine oil prior to casting. In line with BS EN 12390-1 (BS EN 12390, 2021), the freshly mixed concrete was scooped into the oiled 150mm x 150mm x 150mm mold in three layers. Each layer received 25 blows from a tamping rod. The top surface was then polished with a trowel. According to BS EN 12390-2 (BS EN 12390, 2019), the samples were fully submerged in water for 7, 14, 28 and 56 days of curing. From the curing tank, samples were removed for tests on density and water absorption. Finally, a compression testing machine with a 2000KN capacity was used to perform a compressive test on those samples. The capacity of concrete to withstand loads before failing is known as compressive strength. The compressive strength test is one of the various tests conducted on concrete and provides information about the concrete's properties. In line with BS EN 12390-3, the test was conducted (BS EN 12390, 2019).

Table 1a. Chemical composition of sugarcane bagasse ash.

Element	Concentration (% in wt)
Na_2O	0.747
MgO	2.827
Al_2O_3	8.460
SiO_3	64.727
P_2O_3	4.010
SO_3	1.217
CL	0.356
$K_2\,O$	4.019
CaO	6.707
TiO_2	1.004
Cr_2O_3	0.007
Mn_2O_3	0.209
Fe_2O_3	5.574
ZnO	0.0084
SrO	0.050

2.1. Chemical composition on SCBA and cement

These tests were carried out to investigate the chemical compounds present in SCBA and cement at the Central Research Laboratory, Yaba College of Technology, and Lagos State, Nigeria. Atomic absorption spectrometric method was adopted. The results are shown in Table 1a and 1b respectively.

Table 1b. Chemical composition of Dangote 3X (Portland Limestone cement).

Element	Concentration (% in wt)	Classification
SiO_3	20.26	
Al_2O_3	4.96	
Fe_2O_3	3.08	
CaO	53.69	
MgO	1.06	
SO_3	1.53	
$K_2\,O$	0.52	
$Na_2\,O$	0.27	
$K_2\,O + Na_2\,O$	0.79	CEM II- A-L 42.5N
$C_3\,S$	1.217	
$C_2\,S$	40.67	
$C_3\,A$	7.94	
$C_4\,AF$	9.36	
HM	1.9	
LSF	83.45	
AM	1.61	
KM	2.52	

From the chemical analysis result, it was found that the SCBA has a considerably high percentage of silicon oxide- 64.73% compared to Portland Limestone Cement- 20.26% with addition of alumina, silica and ferric ($Al_2\,O_3$ + Si$O_3 + Fe_2\,O_3$) values of 78.8%. It can be traceable to the sum of oxides which are greater than 70% in accordance with ASTM C 618 specification. Chemical analysis of cement was analyzed using X-ray fluorescence method in accordance with BS EN 197-1:2000 & BS 12-78. According to the results in Table 1a, it was concluded that SCBA is a pozzolanic material which has the capacity to be used as partial replacement of cement in concrete mix.

Specific gravity of materials replaced for this study is as follows:
Specific gravity of cement – 3.15
Specific gravity of SCBA – 1.94
Specimen size= 0.15m × 0.15m × 0.15m
No of specimen = 12 cubes
Total volume of concrete = 0.0405m^3
Mix ratio= 1: 2:4
324kg of cement for 1m^3
704kg of fine aggregate (sand) for 1m^3
1320kg of coarse aggregate (granite) for 1m^3
Hence, For 0.0405m^3,
13.12kg of cement needed
28.51kg of sand needed
53.46kg of granite needed
Material volume;
Cement = $\frac{13.12}{14500}$ = 0.009m^3
Sand = $\frac{28.51}{1600}$ = 0.0178m^3
Granite = $\frac{53.46}{1650}$ = 0.0324m^3

2.5% replacement of cement

$\frac{2.5}{100}$ × 0.009 = 0.000225m^3 of cement to be replaced.

If 0.000225m^3 of cement with 1450kg/m^3density is to be replaced with SBCA of density 1950kg/m^3

Volume of SBCA = $\frac{1950 \times 0.000225}{1450}$ = 0.000303m^3 of SBCA
Density of SBCA = 1950kg/m^3
Mass of SBCA = 0.59kg

5.0% replacement of cement

$\frac{500}{100} \times 0.009$ = 0.00045m^3 of cement
Volume of SBCA = $\frac{1950 \times 0.00045}{1450}$ = 0.000605m^3 of SBCA
Mass of SBCA= 1.18kg.

7.5% replacement of cement

$\frac{7.5}{100} \times 0.009$= 0.000675$m^3$ of cement
Volume of SBCA = $\frac{1950 \times 0.000675}{1450}$ = 0.000908m^3 of SBCA
Mass of SBCA = 1.77kg.

10% replacement of cement

$\frac{10}{100} \times 0.009$ = 0.00090m^3 of cement
Volume of SBCA = $\frac{1950 \times 0.00090}{1450}$ = 0.00121m^3 of SBCA
Mass of SBCA = 2.36kg.

From tables 2a and 2b respectively, it was observed that there was a significant difference in the direct substitution due to the specific gravity of SCBA compared to that of cement. Hence, the correct mass of materials used was calculated based on volume replacement.

3. Results and discussion

3.1. Workability of M15 grade of concrete containing Sugarcane bagasse ash

The results of a slump test performed on freshly manufactured SCBA concrete are shown in Fig. 1. Slump was greatest at 10% SCBA content in the mix for all SCBA contents that were observed. This also demonstrated that fresh concrete's slump value was higher with SCBA (9.1- 57.6%). added than it was with ordinary concrete in line with (BS EN 12350, 2009).

Compressive strength measurements for sugarcane content were made after 7 and 28 days of curing, commencing with control mix (0%)-22.50, 25.93 N/mm^2, 2.5%- 19.85, 25.19 N/mm^2, 5.0%-18.37, 23.70 N/mm^2, 7.5%-16.89, 20.30 N/mm^2, and 10%-14.52, 18.96 N/mm^2 in accordance to (BS EN 12390, 2009).

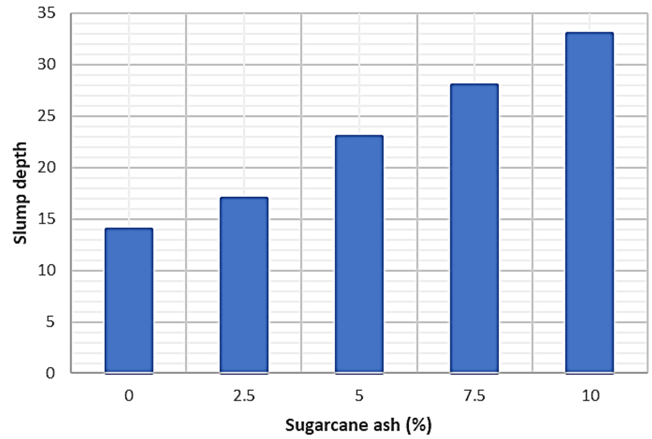

Figure 1. Slump depth versus sugarcane bagasse ash (SCBA).

3.2. Coefficient of Uniformity and Curvature

The effective particle size distribution (PSD) for fine aggregate is 0.21mm, 0.34mm, and 0.56mm, respectively, at 10% (D10), 30% (D30), and 60% (D60) percentage passing. Similar to this,

Table 2a. Mix proportions- Direct mass replacement of materials.

Trial description	Required mass of water	Required mass of granite	Required mass of sand	Required mass of SCBA	Required mass of cement (binder)
(%)	(ltrs)	(kg)	(kg)	(kg)	(kg)
0:100	5.29	42.32	21.16	0.00	10.58
2.5:97.5	5.29	42.32	21.16	0.26	10.32
5.0:95.0	5.29	42.32	21.16	0.53	10.05
7.5:92.5	5.29	42.32	21.16	0.79	9.79
10.0:90.0	5.29	42.32	21.16	1.06	9.52
Total	**26.45**	**211.6**	**105.8**	**2.64**	**50.26**

Table 2b. Mix proportions- Correct mass of materials based on volume replacement.

Trial description	Required mass of water	Required mass of granite	Required mass of sand	Required mass of SCBA	Required mass of cement (binder)
(%)	(ltrs)	(kg)	(kg)	(kg)	(kg)
0:100	4.50	53.46	28.51	0.00	13.12
2.5:97.5	4.50	53.46	28.51	0.59	12.79
5.0:95.0	4.50	53.46	28.51	1.18	12.46
7.5:92.5	4.50	53.46	28.51	1.77	12.14
10.0:90.0	4.50	53.46	28.51	2.36	11.81
Total	**22.5**	**267.3**	**142.6**	**5.90**	**62.32**

for the coarse aggregate shown in Figs. 2 and 3, the effective size at 10% (D10), 30% (D30), and 60% (D60) percentage passing are 11.91mm, 15.24mm, and 19.79mm, respectively. In table 3, the estimated values for the coefficients of uniformity, Cu, and curvature, Cc, for fine and coarse aggregates, respectively, are 2.72 and 1.66, 0.98 and 0.98 as recorded in Table 4. These findings showed that the aggregates only met the AASHTO classification of Cc < 3 for aggregates, showing that both sand and granite were of good quality and that the cu value for the latter was less than 6 because granite and sand are both uniformly graded. The grading of fine and coarse aggregates with homogeneity and curvature coefficients was carried out in accordance with BS EN 933-1 (2012). According to BS EN 12620 (2013), the bulk densities for granite and sand, which are respectively between 1200- 1750 kg/m^3 and 1520-1680 kg/m^3, are within the range of approximate bulk densities utilized in normal weight concrete. As its density decreases with increasing quantity of ash replacement, it is highly advised for use in the creation of lightweight concrete. Additionally, the average water absorption value of sand, which is represented in table 5 as 1.91%, is higher than that of granite, which is 1.64%, but it is lower than the retained water absorption of aggregates, which is limited to 3%. As a result, the aggregates used in this investigation are completely vitrified.

Through a routine analysis process, the average specific gravities (Gs) of 2.60 and 2.62 for fine and coarse aggregates, respectively, were discovered.

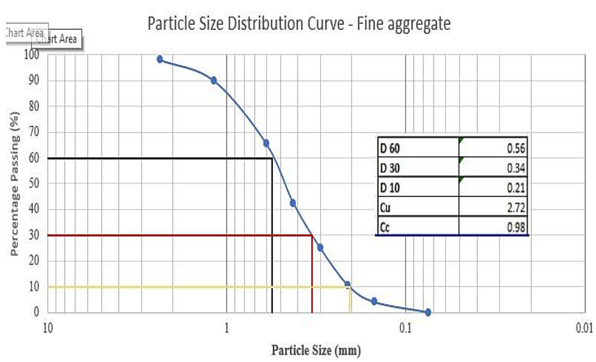

Figure 2. Particle distribution of fine aggregate.

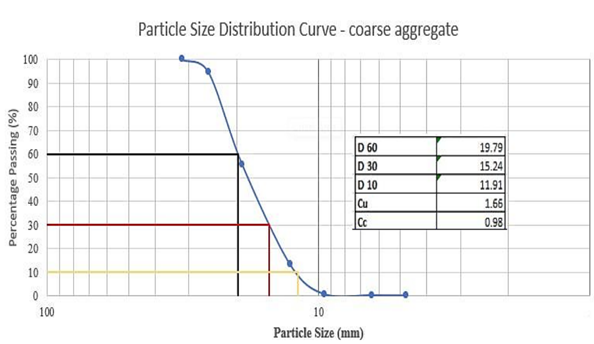

Figure 3. Particle distribution of coarse aggregates.

Table 3. Specific Gravity for aggregate.

Description	A_{rs} (g)	B_{rs} (g)	C_{grnt} (g)	D_{grnt} (g)
Weight of glass jar/Pycnometer (W_1 W_1)	127.0	97.7	851	852
Weight of glass jar + sample (W_2)W_2	185.8	130.0	2824	2912
Weight of glass jar + sample + water (W_3)W_3	411.8	404.6	3690	3760
Weight of glass jar + water (W_4)	373.55	384.8	2460	2501
Result	2.61	2.58	2.66	2.57

Note: rs- River sand; grnt- Granite

Table 4. Coefficient of Uniformity & Curvature.

Aggregates	C_u	C_c
Sand	2.72	0.98
Granite	1.66	0.98

3.2.1. Bulk densities of fine and coarse aggregates

Table 5. Bulk Density for aggregates

Description	A_{rs} (kg)	B_{grnt} (kg)
Mass of cylinder + Mass of sand (M_1)	1422	1414
Mass of cylinder (M_2)	704	704
Mass of sand ($M_1 - M_2$)	718	710

3.2.2. Water absorption of fine and coarse aggregates

Table 6. Water absorption for fine and coarse aggregates.

Description	A_{rs}	B_{rs}	C_{grnt}	D_{grnt}
Weight of wet sample (W_1 W_1)W_1	112	101	84.0	74.0
Weight of dry sample (W_2)	110	99	83.0	72.5
Result	1.80%	2.02%	1.20%	2.07%

3.3. Initial and final setting time of concrete

For the manufacturing of typical concrete mix, the curves in Figs. 4 and 5 show a starting setting time for Dangote cement of 56 minutes and a total setting time of 280 minutes. The compound present in cement known as tricalcium aluminate (C3 A) component of the mixture, which plays a crucial role in improving the hydration in the early hours, can be seen as the reason why all specimens incorporated with SCBA were found to have higher initial and final setting times. It reacts with water quickly as is typical and may cause paste to immediately stiffen. The addition of SCBA to the concrete mix, as shown in table 6, dramatically increased the initial and ultimate setting time values.

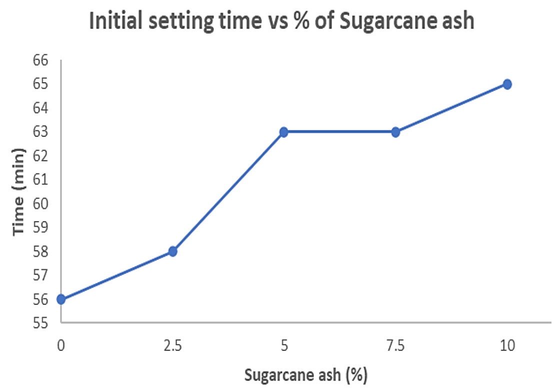

Figure 4. Initial setting time versus % of sugarcane ash replacement.

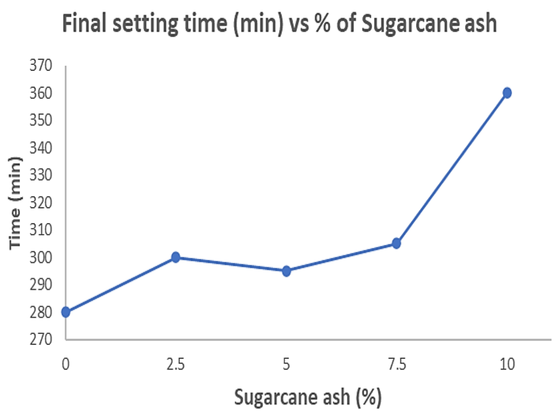

Figure 5. Final setting time versus % of sugarcane ash replacement.

3.4. Compressive Strength

The 10% optimum amount of SCBA boosts the compressive strength of concrete, however as the replacement percentage increased, the newly-poured and cured concrete (LeBow, 2022). For setting time values, 56mins for initial and 280mins for final at 0%- cement only was compared with 65 mins and 360mins respectively revealed that increase in SCBA varying proportions increases both the initial and final setting time values as recorded in Table 7. For all mix ratios, the compressive strength of the concrete cubes increases with curing age and decreases as SCBA content rises. When cement is substituted with SCBA in amounts of 2.5, 5, 7.5, and 10%, compared to the control, compressive strength is reduced by 2.94, 9.40, 27.73, and 36.76%, respectively. The fluctuation of compressive strength N/mm2 with curing ages is shown in Fig. 6. Fig. 7 depicts the change in compressive strength of hardened concrete when the percentage of SCBA is increased in line with in accordance to (BS EN 12390: 2009). At 28 days of curing, OPC concrete (0% ash) has a higher compressive strength than concrete with varying SCBA to cement content. Compressive strength measurements for sugarcane content were made after 7 and 28 days of curing, commencing with control mix (0%)-22.50, 25.93 N/mm^2, 2.5%- 19.85, 25.19 N/mm^2, 5.0%- 18.37, 23.70 N/mm^2, 7.5%-16.89, 20.30 N/mm^2, and 10%-14.52, 18.96 N/mm^2. On the 28th day, they all achieved characteristics strengths more than 15MPa with respective values of 25.93MPa and 18.96MPa for 0% and 10% replacement as recorded in Table 8.

Table 7. Initial and final setting time of sugarcane ash.

Percentage Replacement (%)	Initial setting time (Min)	Final setting time (Min)
0	56	280
2.5	58	287
5.0	63	295
7.5	63	305
10.0	65	360

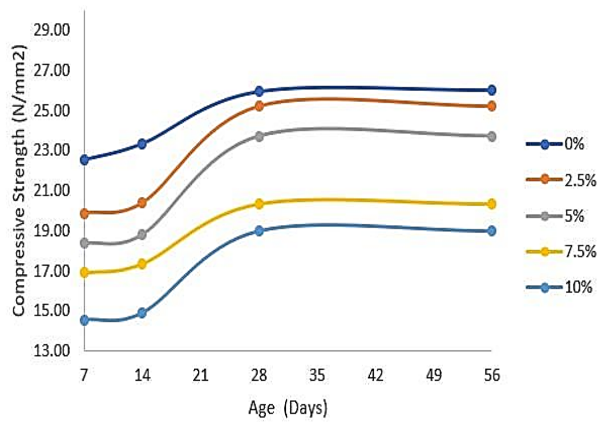

Figure 6. Compressive strength values versus Age of curing.

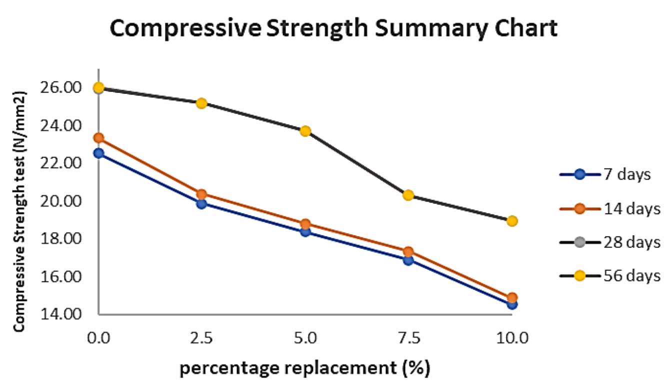

Figure 7. Compressive strength values versus % of SCBA replacement.

Table 8. Average Compressive strength values for 7, 14, 28 and 56 days.

Sample Number	Percentage replacement (%)	Average Compressive Strength value ($\frac{N}{mm^2}$*N/mm^2*)			
		7 days	14 days	28 days	56 days
1	0.0	22.52	23.33	25.93	26.00
2	2.5	19.85	20.37	25.19	25.19
3	5.0	18.37	18.81	23.70	23.70
4	7.5	16.89	17.35	20.30	20.30
5	10.0	14.52	14.87	18.96	18.96

4. Conclusions

Constant water cement ratio was used throughout in studying the effect of sugarcane ash on the workability, density, water absorption, setting time and compressive strength of concrete for various percentage replacements with 2.5, 5.0, 7.5 and 10.0% respectively. The following conclusions were drawn from the research work which includes:

i. The calculated target mean strength of 20.78N/mm2 was achieved. This may be as a result of conducting the experiment in a well confined environment with other factors such as adequate mixing, placement, compaction and reactivity of SCBA.
ii. Workability of concrete increases by increasing the percentage of replacement of SCBA in concrete with 10.0% replacement giving the highest workable concrete of 33mm compared with the other replacements.
iii. Initial and final setting time increases with increase in percentage of sugarcane ash because particle size of bagasse ash is finer than cement which makes it absorbs more water as a result of higher density and lower specific gravity.
iv. For control, the compressive strength was 25.93$\frac{N}{mm^2}$N/mm^2 higher than the calculated target mean strength. This can be used for reinforced concrete with normal weight aggregate.
v. The compressive strength of all concrete cubes increases with curing age and decreases as the SCBA content increases. The percentage reduction of compressive strength for 2.5, 5.0, 7.5 and 10% replacement of SCBA compared to control are 2.94, 9.40, 27.73 and 36.76% respectively.
vi. Sugarcane ash is a good and effective pozzolan which can be recommended for use as partial replacement of cement in concrete production at a percentage up to 10%. For environmental sustainability, sugarcane ash is utilized for the production of lightweight, durable and cheap concrete. Since it is readily available across the country.

Conflict of interest

The authors have no conflict of interest to declare.

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